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November 30, 1999

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Mr. Donald S. Abelson
International Bureau
Federal Communications Commission
Room 6-C750
445 Twelfth Street, S.W.
Washington, D.C. 20554

Re: 18 GHz Blanket Licensing Rulemaking, *IB Docket No. 98-172*

Dear Don:

As you know, Teledesic Corporation is building the world's first NGSO FSS satellite system, a system capable of bringing advanced broadband services to even the most remote regions of the world. I write on behalf of Teledesic, to explain in detail the very compelling technical and policy reasons why the FCC should adopt its own proposal to designate a full 500 MHz for NGSO FSS downlinks, and reject the substitute band plan that has been pushed by terrestrial microwave interests.

Based on the results of World Radiocommunication Conferences in 1995 and 1997, the Teledesic NGSO FSS network has been designed to use a single 500 MHz downlink carrier in the 18.8-19.3 GHz band. If the downlink band identified for NGSO FSS were to remain shared with FS on a co-primary basis, coordination of each individual NGSO FSS user terminal would clearly be required. However, in 1998 the FCC proposed to segment the band between satellite and terrestrial uses and designate the 18.8-19.3 GHz band for NGSO FSS, making blanket licensing possible across the entire 500 MHz. Adoption of the FCC's 18 GHz band plan would be a major victory for users of both satellite and terrestrial services, as any individual user would be able to receive satellite service or terrestrial service or both, without worrying about "exclusion zones" created by a neighbor's choice of service.

Unfortunately, FS interests are proposing an alternative to the FCC's proposed band plan that would destroy these benefits, at least as far as NGSO FSS is concerned. The FS-sponsored band plan would designate the upper 40 MHz of the NGSO FSS band (the portion

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from 19.26-19.3 GHz) primarily for FS use. However, with a single 500 MHz downlink carrier, 40 MHz of FS interference blocks deployment of an NGSO FSS user terminal just as effectively as if there were interference across the full 500 MHz.

If such a band plan were adopted, Teledesic would have only four options, none of them good. The attached technical discussion explores these options in great detail, but the options and their defects can be summarized as follows:

- Option One: Attempt to mitigate the FS interference. Teledesic has investigated every mitigation technique that it can think of, but it simply is not possible to mitigate the 40 MHz of interference as long as the satellite downlink consists of a single 500 MHz carrier.

- Option Two: "Break up" the downlink carrier into multiple downlink carriers of narrower bandwidth. Teledesic has actually tried to implement this approach in its licensed 288-satellite design. However, further study of this concept has demonstrated that using multiple downlink carriers is much less spectrally efficient than using a single downlink carrier, even if one only considers the effect within a single beam. In addition, there are "spillover" effects between and among beams, such that reduced bandwidth operations in one beam will adversely affect Teledesic's capacity and quality of service in adjacent areas even if the full 500 MHz is available in the adjacent area. As a result, this option must be regarded only as a "last resort" for the exceptional case in which Teledesic must provide reduced-bandwidth service in a very unfavorable spectrum environment in order to meet the global requirements of, for example, a large multi-national corporation. This is by no means a general solution to the problem of incompatible terrestrial uses.

- Option Three: Redesign the satellites to be capable of using either a 460 MHz downlink carrier or a 500 MHz downlink carrier, depending on whether FS interference is present in the upper 40 MHz. Although it is theoretically possible to build an NGSO FSS system that can use different frequency plans and/or channeling in different countries or areas, there are insurmountable practical obstacles, including massive increases in hardware cost and drastic reductions in capacity. The network must be optimized for data packets of a certain, constant size. With 500 MHz of bandwidth, the optimal packet size will use all 500 MHz. If some beams are using only, say, 460 MHz of capacity, then each regular packet would need to be broken into two smaller packets, each with its own header, resulting in a 50% loss of efficiency. Alternatively, optimizing for 460 MHz would impose a capacity penalty on *all* users – even those who operate in areas where the full 500 MHz is available – solely because of the need to avoid scattered FS links in a handful of urban areas.

- Option Four: Redesign the satellites to operate in only 460 MHz of spectrum. Obviously, Teledesic could simply reduce its downlink bandwidth from 500 MHz to 460 MHz. However, since other broadband satellite systems will be operating with 750 MHz of exclusive spectrum, or even more, and since this is the only band identified internationally for NGSO FSS use without the burden of protecting the entire GSO arc, the loss of 40 MHz around the globe would be a grievous injury to this nascent service. More

> importantly, there is no reason to expect that the same 460 MHz would be available globally. A system with a single carrier of 460 MHz would thus encounter the same difficulties that the FS-sponsored plan would cause for Teledesic's single 500 MHz carrier – except that the situation would be much worse as a political matter because the globally uniform 500 MHz would be in tatters.

There is thus no technological miracle that will allow Teledesic to use the upper 40 MHz everywhere except the relatively few places where terrestrial FS links are deployed. Consequently, *adoption of the FS-sponsored band plan would defeat the whole point of the 18 GHz rulemaking in that it would leave NGSO FSS operators in the position of trying to coordinate the placement of each individual user terminal.* There would be no practicable way to change the network design to accommodate the FS-sponsored plan, so the only reasonable thing to do would be to design the network for 500 MHz and put up with the coordination burden and the exclusion zones arising from co-primary FS use. The Commission itself, in its NPRM, has made clear what a poor policy result this would be, and we urge you to avoid it.

It is tempting to say that if the Commission adopts the FS-sponsored plan, then insofar as NGSO FSS systems are concerned the whole rulemaking might just as well never have happened. But that would be incorrect, because NGSO FSS systems would actually be *worse off than under a co-primary sharing regime.* At present, it is difficult to coordinate use of the full 500 MHz for NGSO FSS in some areas, but once it is coordinated, it is protected from later encroachment. However, if the Commission designates the upper 40 MHz for FS, then even a fully coordinated NGSO FSS user terminal using all 500 MHz of spectrum could be "ejected" by a later-deployed FS link in the top 40 MHz. The Commission's original proposal of 500 MHz for NGSO FSS downlinks was a victory for both FS and NGSO FSS users; the FS-sponsored band plan now under consideration would instead practically kill off the NGSO FSS industry before it is launched.

The importance of the FCC's continued leadership on this matter cannot be overstated. Many countries around the world are considering the appropriate use of the 18 GHz band, and the FCC's NPRM has been very influential so far in persuading other administrations to halt licensing of FS in the full 500 MHz and reserve this spectrum for NGSO FSS use. Any nibbling at the edges of the band can be expected to set off a chain reaction overseas, resulting in a hodge-podge of frequency bands worldwide that might actually kill the service before it is launched. In one stroke, the Commission would be destroying the uniform global allocation for which the United States fought so hard at two successive World Radiocommunication Conferences. This would be particularly damaging now, because it would amount to a retraction of the NPRM proposal for a full 500 MHz. This could not fail to be seen overseas as US backsliding on the promise and viability of NGSO FSS systems.

Furthermore, the benefit to the FS of gaining exclusive access to this 40 MHz pales in comparison to the importance of these same frequencies for NGSO FSS systems like Teledesic. According to Comsearch, there are only 340 FS links licensed *in the whole United States* between

19.26 GHz and 19.3 GHz. It would defy reason to cripple the entire NGSO FSS industry worldwide in order to protect 340 individual links *that Teledesic is willing to pay to relocate*.

In conclusion, we urge you to review the attached technical information with your staff. NGSO FSS has tremendous potential to serve the public interest, here in the United States and around the globe. It would be a public policy disaster if the Commission were to destroy the potential of such systems globally merely to avoid the relocation of a relatively small number of FS links operating at 19.26-19.3 GHz.

Sincerely,

Mark A. G

Mark A. Grannis

cc: Richard B. Engleman
Julie Garcia
Jennifer Gilsenan
Edward R. Jacobs
Karl A. Kensinger
F. Ronald Netro
Harold Ng
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30 November 1999

The Teledesic NGSO FSS Downlink Requires 500 MHz

Based on the results of WRC-95 and WRC-97, the Teledesic NGSO FSS network has been designed to use a single 500 MHz downlink carrier in the 18.8-19.3 GHz band. If instead the FCC were to designate the upper 40 MHz of the NGSO FSS band (the portion from 19.26-19.3 GHz) primarily for FS use, as some FS interests are suggesting, any NGSO FSS network using a single downlink carrier would be unable to mitigate the FS interference in the upper 40 MHz. With a single 500 MHz downlink carrier, 40 MHz of FS interference blocks deployment of an NGSO FSS user terminal just as effectively as if there were interference across the full 500 MHz.

If such a band plan were adopted, Teledesic would have only four options, none of them good:

1. Attempt to mitigate the FS interference;
2. "Break up" the downlink carrier into multiple downlink carriers of narrower bandwidth;
3. Redesign the satellites to permit use of either a 460 MHz downlink carrier or a 500 MHz downlink carrier, depending on whether FS interference is present in the upper 40 MHz.
4. Redesign the satellites to operate in only 460 MHz of spectrum;

For the reasons discussed below, not one of these options would provide a practicable solution to the interference problem. Adoption of the FS-sponsored band plan would therefore leave Teledesic in the position of trying to coordinate the placement of each individual user terminal – and being unable to provide service to some customers because of the large exclusion zones created by nearby FS use. This paper examines the technical factors that lead to this conclusion.

Option One: Attempt to Mitigate the FS Interference

1) 40 MHz of FS interference blocks a single carrier 500 MHz NGSO downlink

If the total interference power from a single FS transmitter is comparable to the power of the 500 MHz NGSO downlink signal, then the NGSO downlink performance will be seriously impaired. This is true no matter how small the bandwidth of the FS signal. The analysis in Annex 1 shows that a typical FS transmitter operating in just 6.3 MHz of this upper 40 MHz can create an exclusion zone on the order of 40 km^2. For a typical FS transmitter with a 28 MHz bandwidth, the exclusion zone increases to over 55 km^2. Therefore, *confining FS operations to the upper 40 MHz of the 500 MHz band does not solve the problem of harmful interference into the NGSO user terminals.*

2) Filtering off the upper 40 MHz of the band in a NGSO user terminal is not a feasible solution

Annex 2 explains in detail why it is not possible to enable coexistence of FS and NGSO FSS in the upper 40 MHz of the 500 MHz NGSO FSS downlink band. The analysis shows that it is not feasible to use a filter to remove FS interference in the upper 40 MHz of the frequency band. In addition to reducing the received signal power, such *filtering would introduce inter-symbol interference (ISI) that significantly degrades the performance of the link.* (ISI distorts the received signal, preventing proper demodulation.)

3) It is not feasible to mitigate the distortion that would be caused by the filtering discussed above

One may argue that in theory, inter-symbol interference (ISI) can be mitigated through equalization or maximum likelihood sequence detection. However, equalization will not work for this problem because it would involve implementing the inverse of the null filter which would just re-introduce the FS interference to the received signal.

Maximum likelihood sequence detection can be efficiently implemented using a Viterbi decoder. However, the number of states in the associated trellis is 2^n, where n is the number of non-zero values in the ISI that must be removed. Any filter to attenuate 40MHz of a 500MHz signal will introduce ISI over many adjacent symbols (see Figure 3 of Annex 2). This renders maximum likelihood sequence detection not feasible because the number of states in the trellis is prohibitively large.

Option Two: "Break Up" the Downlink Carrier

4) Using a full-bandwidth, single carrier beam is the most spectrally efficient, cost effective downlink design for a broadband NGSO system

Given that it is not feasible to operate a 500 MHz downlink in the presence of FS interference in the upper 40 MHz, it might be proposed that Teledesic redesign its system to break-up the 500 MHz into multiple, narrower bandwidth channels and incorporate multi-carrier beams. One could argue that this would mean that only one carrier would need to be turned off to serve areas where FS transmitters are operating in the upper 40 MHz of the downlink band. Teledesic has examined such multi-carrier downlink configurations in detail. To achieve the same performance on a multi-carrier system would mean breaking the packet up and transmitting it on several carriers, which adds significant complexity and expense and is much less spectrally efficient.

Annex 3 describes in detail inefficiencies associated with breaking up the downlink into multiple smaller bandwidth carriers. The conclusion is that use of a single wide-band carrier is the optimal downlink design because it minimises the required NGSO downlink power, maximises the downlink capacity and spectral efficiency, and enables the use of less complex and less expensive satellite and user equipment.

5) Operating single-carrier beams of 270, 135 or 67.5 MHz in any satellite footprint encompassing major market areas would degrade the service and threaten the system's economic viability.

The above points have shown that it is not feasible to operate a 500 MHz downlink in the presence of FS interference in the upper 40 MHz. Nor is it feasible to operate multiple carriers per beam. In view of this, it might be proposed that Teledesic operate reduced-bandwidth, single-carrier beams to avoid FS interference in the upper 40 MHz of the NGSO downlink band.

Teledesic's 288-satellite modification application requested the flexibility to implement beams of 270, 135 and 67.5 MHz, in addition to the standard 500 MHz downlink beams. At the time of the filing, it was hoped that these reduced bandwidth beams would facilitate coordination around incompatible terrestrial uses (and solve coordination situations with GSO networks that have ITU priority over the Teledesic network, which has not proven necessary). However, further study of these narrower-bandwidth beams has made clear that this is a "last resort" solution for exceptional cases, not a general solution to FS interference. The use of narrower bandwidths would reduce the capacity in a beam by at least the ratio of the reduced bandwidth to 500 MHz (*e.g.*, a 270 MHz beam would have less than 54% of the capacity of a 500 MHz beam). This does not account for the network capacity reduction due to the other effects discussed below.

Even if the reduced bandwidth operations in one area did not degrade network performance in areas where the full 500 MHz is available, this would be a serious detriment not only to Teledesic, but to NGSO FSS users. The effect on Teledesic would be to curtail the amount of capacity (and therefore revenue) available in the most densely populated areas by more than 50%. This would threaten the economic viability of the system, as it would amount to a decision that Teledesic may not offer *most potential users* more than 270 MHz of capacity. Moreover, from a user's perspective, it would reduce the maximum capacity available in a given area. This would essentially throw away one of the most important benefits of NGSO FSS systems: the ability to bring the most advanced communications capabilities to *all* areas of the globe, regardless of population density or level of development.

Furthermore, there are "spillover" effects of reduced bandwidth operation in selected countries. That is, for a variety of technical reasons, reduced bandwidth operation on one beam introduces inefficiencies into the operation of other beams. As a result, Teledesic's recent capacity analyses show that where there are two or more countries within a single satellite's footprint, and one of them makes less than the entire 500 MHz downlink band available, reduced bandwidth operation in that country would be so costly that it might only make sense in order to satisfy very large customer requirements, such as the global requirements of a large multi-national corporation. Otherwise, Teledesic might be better off not providing service there at all. Only by avoiding that country altogether could Teledesic preserve its ability to achieve the desired efficiencies and maximize the available capacity in adjacent countries where the full 500 MHz is available.

<u>Option Three: Redesign the satellites to be capable of using either 500 MHz or 460 MHz</u>

6) What about adding the capability to use 460 MHz beams where necessary?

Given that it is not economically viable to operate single-carrier beams of 270, 135 or 67.5 MHz in general, it may be proposed that Teledesic redesign its system to include 460 MHz bandwidth beams for use in areas where FS transmitters operate in the upper 40 MHz of the NGSO downlink band. This would be very spectrally inefficient for the reasons described in the following two items.

7) Phased-array antenna technology enables very high speed switching, but beams sharing the same aperture must be synchronous

Current technology enables NGSO FSS satellites to switch the pointing of their downlink beams on a packet-by-packet basis. This is made possible with today's phased array antennas that can perform beam switching in a negligible time (less than 100 nanoseconds). However, switching of the multiple beams sharing a common aperture must be synchronous to avoid random phase shifts in the received signal. This is further explained in Annex 4. The consequence is that *the data packet frame duration must be fixed* and therefore the number of bits that can be transmitted in a frame is directly proportional to the bandwidth of the downlink beam.

8) Due to the requirement for synchronous data packet bursts, 460 MHz beams would in practice provide only half the capacity of the 500 MHz beams

The Teledesic data packets are sized to fit the 500 MHz bandwidth signal. This makes the optimal use of the spectrum and network resources. The packets are designed to be as long as possible to minimise the network overhead associated with packet preamble, etc., without being so long as to negatively impact the network's ability to simultaneously serve a large number of users with a high QoS. To enable reduced bandwidth downlink operation, the normal data packets would have to be split into multiple packets, each with its own packet preamble and fewer payload (user data) bits. This is required since the network operates synchronously with a constant frame duration as explained above. Therefore, to accommodate *a 460 MHz bandwidth mode would result in a 50% inefficiency because the normal (500 MHz) packets would each have to be sent as two 460 MHz packets.* Annex 5 explains the technical details of the significant spectral wastage that would occur whenever such a 460 MHz beam were operated.

9) Requiring multiple bandwidths and center frequencies as a function of geographical area is not practicable

Use of reduced bandwidth beams in any NGSO FSS system results in a direct reduction of capacity in those beams by at least a factor equal to the reduction in bandwidth (actually substantially more capacity than this would be lost due to other considerations such as statistical multiplexing efficiency). It would also reduce the ability of a satellite to provide capacity to areas adjacent to a reduced bandwidth beam's footprint due to the frequency re-use distance constraint required to avoid self-interference. This is because the time that a reduced bandwidth beam must dwell on a particular spot increases linearly with the number of packets delivered.

Therefore, the time that 500 MHz beams would be allowed to serve areas or countries in the satellite footprint that are within the frequency re-use distance of any reduced bandwidth beams would be significantly reduced.

10) Operating reduced bandwidth beams to serve specific areas to avoid FS interference would be unduly burdensome

Teledesic user terminals are designed to receive on a single channel of 500 MHz bandwidth. If it were necessary to operate reduced bandwidth beams to fulfill a requirement in one area, the user terminals deployed in that specific area affected would need to be designed to receive on the required reduced bandwidth channel. In addition to the loss of capacity discussed above, this would adversely impact the transportability of user equipment and result in more expensive user equipment. Given the different FS band plans around the world, this could result in different standards for the user equipment in every country.

Furthermore, the need to protect the use of the 40 MHz at any location would necessarily require the coordination of every 500 MHz NGSO terminal. This would preclude the ubiquitous nature of NGSO FSS, increase coordination costs to the FS, and place a disproportionate and unacceptable burden on the user of the NGSO FSS equipment. Such coordination would also decrease the efficient use of the spectrum by preventing either service from growing to its full potential.

Option Four: Redesign the Satellites to use only 460 MHz of Spectrum

11) Why not just operate a single carrier of 460 MHz everywhere?

One reason is obvious: 460 MHz of capacity is less than 500 MHz of capacity. Since other broadband satellite systems will be operating with 750 MHz of exclusive spectrum, or even more, and since this is the only band identified internationally for NGSO FSS use without the burden of protecting the entire GSO arc, the loss of 40 MHz around the globe would be a grievous injury to this nascent service.

A less obvious, but even more important reason is that there is no reason to expect that the same 460 MHz would be available globally. At present, thanks in large part to the extraordinary diplomatic efforts of the United States over the past five years, we have global agreement on 500 MHz for NGSO FSS downlinks in 18.8 – 19.3 GHz. Coordination may be required in some countries, and some countries may "carve out" specific sections of the band for incompatible uses. But each country knows that the full 500 MHz runs from 18.8-19.3 GHz, and that any departure from those frequencies is a step away from global uniformity and the full potential of NGSO FSS technology.

An FCC decision to abandon that uniformity in order to protect incumbent FS operators serving a very small number of users would change the presumptive NGSO FSS designation overnight. Other countries would surely follow suit, except that instead of carving out the 40 MHz occupied by FS operators in the United States, each would carve out whatever amount is required to protect *its* incumbent FS systems. A system with a single carrier of 460 MHz would thus encounter the same difficulties that the FS-sponsored plan would cause for Teledesic's single 500 MHz carrier – except that the situation would be much worse as a political matter because the globally uniform 500 MHz would be in tatters.

Annex 1

AN ANALYSIS OF THE POTENTIAL INTERFERENCE FROM POINT-TO-POINT FS TRANSMITTERS INTO NGSO FSS EARTH STATION RECEIVERS OPERATING IN THE 18.8-19.3 GHz BAND

Background

Historically, the Fixed-Satellite Service (FSS) and point-to-point Fixed Service (FS) systems have been able to share the same frequencies without difficulty. Both services were used primarily for trunking applications, so coordination involved a relatively small number of large, expensive terrestrial links and a relatively small number of large, expensive satellite earth stations. This was not unduly burdensome for either service.

As technological development has facilitated the use of higher frequencies, however, this traditional sharing paradigm has broken down. The propagation characteristics of the frequencies above 18 GHz permit both satellite and terrestrial operators to use much smaller antennas and less expensive equipment, and consequently both satellite and terrestrial operators can tailor their service offerings to a much larger class of end users. These characteristics lead to the widespread deployment of both types of service in much higher densities with the result that it is difficult for either service to mitigate against so many interfering stations. As this deployment proceeds, the density of transceiver stations can quickly reach levels which render co-frequency sharing unfeasible. It becomes impractical to coordinate the growing numbers of FS stations and satellite user terminals. The percentage of a region's area where terminals are excluded becomes increasingly large.

Overview

This annex presents analysis of the interference that could be generated by typical FS transmitters into non-geostationary satellite orbit (NGSO) FSS user terminals were they to operate co-frequency and in close proximity, in the18.8-19.3 GHz band. The FS stations impose regions around each FS transmitter in which reliable operation of NGSO user terminals may be precluded due to excessive interference. These blocked regions are referred to as "exclusion zones." A single point-to-point FS transmitter will typically impose a circular exclusion zone in the area immediately surrounding it (off-axis directions) and a highly elliptical exclusion zone extending a long distance along its on-axis direction of transmission.

Exclusion zone created by a single point-to-point FS transmitter

FS transmitters deployed in the band 18.8–19.3 GHz could cause severe interference to NGSO FSS user terminals. To estimate the percentage of service area that may result in blockage of LEOSAT-1 Broadband NGSO services, exclusion zones can be determined around each FS transmitter operating within the 18.8–19.3 GHz band in a given area. The equations and ITU-R Recommendations used in the calculation of the exclusion zones are presented in detail in Appendix A.

Figure 1 presents an example exclusion zone calculated using the parameters of a typical 6.3 MHz point-to-point FS transmitter with a 0.6-m parabolic dish. The boundary in Figure 1 is based on a single-source, long-term interference allowance of 6% of the NGSO user terminal system noise (i.e., I/N = -12.2 dB) under clear sky, clear terrain conditions. NGSO user terminals would need to be kept outside of this contour in order to guarantee that interference levels from the FS transmitter would be acceptably low. An analysis taking account of natural and man-made terrain blockages could indicate a reduction of this area in certain directions. Table 1 presents the parameters used to generate Figure 1 along with an example interference calculation for the 6.3 MHz, 0.6-m antenna case. It can be observed in Figure 1 that the diameter of the exclusion zone around the terminal can be nearly 1 km and the length of the exclusion zone in the direction of transmission can be over 40 km. It is significant to note that just this single typical 6.3 MHz FS transmit station results in a potential exclusion zone with a total area of 41.2 km^2.

TABLE 1

Parameters used in exclusion zone interference calculation corresponding to a 0.6 m, antenna, 6.3 MHz FS transmitter in the database

Parameter	Value	Comments
FS Transmit Power, dBW	-10	(+20 dBm)
FS Miscellaneous Losses, dB	-1	Feeder Loss, etc.
FS Transmit Gain, dBi	39	0.6 m Dish, 0.55 efficiency
Tx Discrimination, dB	0	Mainbeam assumed
FS Transmit BW, dB/Hz Interfering Path Length, km	68.0 10	(6.3 MHz) Example Distance
Free Space Loss, dB	-138	At 19 GHz
Atmospheric Loss, dB	-0.8	At 7.3 g/m^3, 20°C
NGSO Receive Gain, dBi	34.1	
NGSO Rx Discrimination, dB	-37.3	Off-boresight angle >48°
Interfering Power, dBW	-114.0	
NGSO Noise Power, dBW	-117.0	288°K System Noise Temp
Resulting I/N, dB	+3.0	Exceeds -12.2 dB threshold value by 15.2 dB

TABLE 2

Parameters used in exclusion zone interference calculation corresponding to a 0.6 m antenna, 28 MHz FS transmitter in the database

Parameter	Value	Comments
FS Transmit Power, dBW	-9	(+21 dBm)
FS Miscellaneous Losses, dB	-1	Feeder Loss, etc.
FS Transmit Gain, dBi	39	0.6 m Dish, 0.55 efficiency
Tx Discrimination, dB	0	Mainbeam assumed
FS Transmit BW, dB/Hz Interfering Path Length, km	74.5 10	(28 MHz) Example Distance
Free Space Loss, dB	-138	At 19 GHz
Atmospheric Loss, dB	-0.8	At 7.3 g/m^3, 20°C
NGSO Receive Gain, dBi	34.1	
NGSO Rx Discrimination, dB	-37.3	Off-boresight angle >48°
Interfering Power, dBW	-113.0	
NGSO Noise Power, dBW	-117.0	288°K System Noise Temp
Resulting I/N, dB	+4.0	Exceeds -12.2 dB threshold value by 16.2 dB

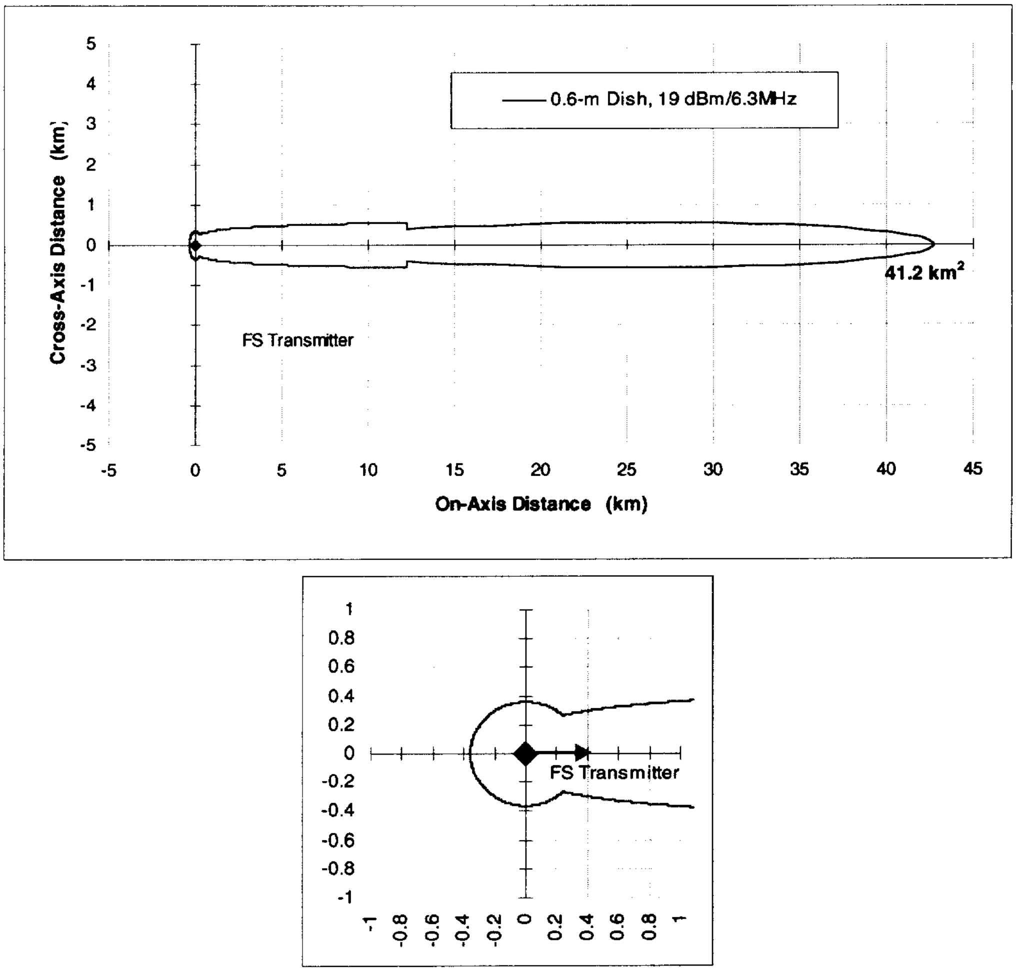
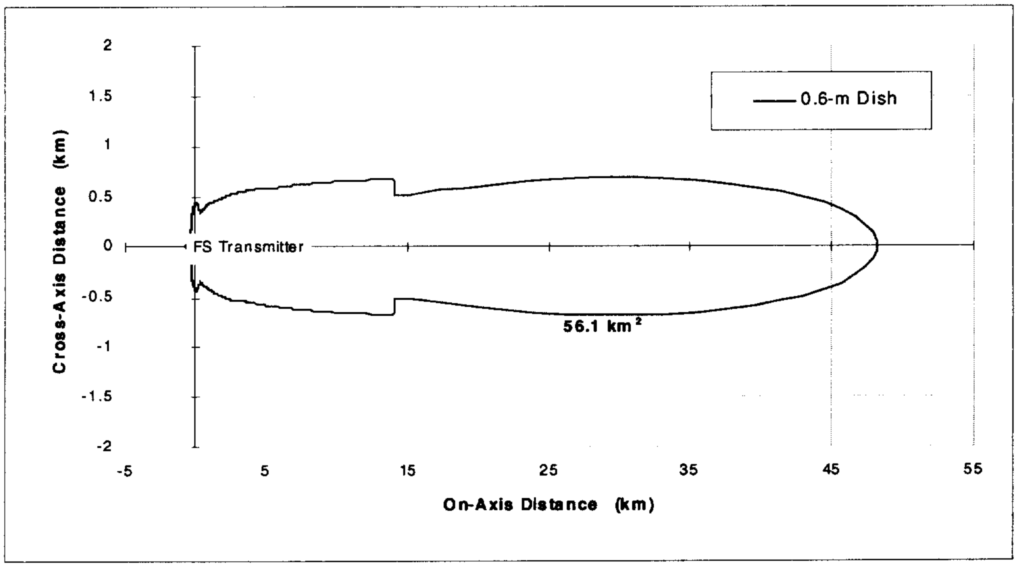


FIGURE 1

Exclusion zone for LEOSAT-1 standard terminals created by one typical 6.3 MHz FS transmitter

Table 2 presents the parameters used to generate Figure 2 along with an example interference calculation for the 28 MHz, 0.6-m antenna case. It can be observed in Figure 2 that the diameter of the exclusion zone around the terminal can be nearly 1 km and the length of the exclusion zone in the direction of transmission can be well over 45 km. Beyond about 40 km, line of sight interference is eliminated (unless the FS transmitter is located far above ground level). Further study is required to determine if other propagation mechanisms such as ducting or tropospheric scattering would create interference beyond 40 km from the FS transmitter. It is significant to note that just this single typical 28 MHz FS transmit station results in a potential exclusion zone with a total area of 56.1 km^2.



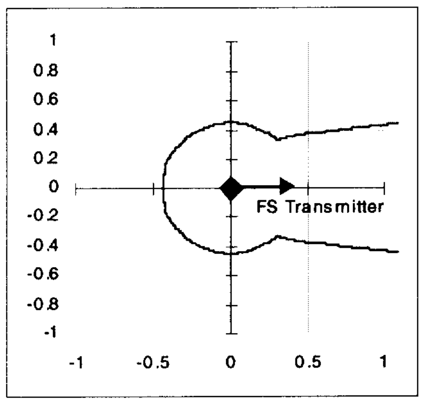


FIGURE 2

Exclusion zone for LEOSAT-1 standard terminals created by one typical 28 MHz FS transmitter

Conclusion

FS stations impose regions around each FS transmitter in which reliable operation of NGSO user terminals may be precluded due to excessive interference. These blocked regions are referred to as "exclusion zones." In the case of a typical point-to-point 6.3 MHz FS transmitter employing a 0.6 m antenna, this annex shows that the diameter of the exclusion zone in the off-axis directions around the terminal can be nearly 1 km and the length of the exclusion zone in the direction of transmission can be well over 40 km (see Figure 1). In the case of a typical point-to-point 28 MHz FS transmitter, this paper shows that the diameter of the exclusion zone in the off-axis directions around the terminal can be nearly 1 km and the length of the exclusion zone in the direction of transmission can be well over 45 km (see Figure 2). The total exclusion zone area for just one of these typical FS transmitters is more than 40 km^2.for the 6.3 MHz case and more than 50 km^2 for the 28 MHz case. An analysis taking account of natural and man-made terrain blockages could indicate a reduction of this area in certain directions.

The conclusion of this analysis is that deployment of FS stations anywhere in the paired bands 18.8–19.3 GHz (downlink) and 28.6–29.1 GHz (uplink) could significantly constrain the placement of NGSO FSS user terminals. This is particularly true for areas that have a high density of FS stations. The results indicate that as the FS deployment density increases, the placement of NGSO FSS user terminals becomes more constrained.

Appendix A to Annex 1

Exclusion zone calculation

The exclusion zone geometry associated with FS/FSS co-frequency operation can be calculated using standard link equations. The boundary is based on a single-entry, long-term interference allowance of 6% of the receiver system noise. The interference power is calculated using the following equation:

$$I = (P_{Tx})_{FS} - (L_F)_{FS} + (G_{Tx}(j))_{FS} - L(d) + (G_{Rx}(f))_{NGSO} - BW_{cor}$$

where,

$(P_{Tx})_{FS}$	**FS transmitter power [dBm]**
$(L_F)_{FS}$	**FS transmitter loss [dB]**
$(G_{Tx}(\varphi))_{FS}$ [dB]	**FS gain in the direction of the NGSO terminal (ITU-R F.699-4)**
φ	**Angle from FS transmit boresight [deg]**
L(d)	**Signal loss associated with path distance, $L_{FSL} + L_{atm}$ [dB]**
L_{FSL}	**Free space loss, $\approx 92.44 + 20 \times \log_{10}(d \times f)$ [dB]**
d	**FS and NGSO terminal separation [km]**
f	**frequency [GHz]**
L_{atm}	**atmospheric loss, $\gamma_a \times d$, (ITU-R P.676-3) [dB]**
γ_a [dB/km]	**specific attenuation, ($\approx$ 0.08 dB/km for 7.5 g/m^3, 20°C)**
$(G_{Rx}(\phi))_{NGSO}$	**NGSO gain in the direction of the FS transmitter (AP29) [dB]**
ϕ	**Angle from NGSO receive boresight [deg]**
BW_{cor}	**Overlap bandwidth correction, the higher of 0.0 or**

$$10 \times \log 10\left(\frac{(BW_{Tx})_{FS}}{(BW_{Rx})_{NGSO}}\right) \quad [dB]$$

The FS transmitter power, feeder loss, and frequency are obtained directly from the Argentina fixed service database. If not provided directly, the FS transmitter peak gain is estimated from the given antenna diameter, frequency, and assumed 0.55 antenna efficiency, using

$$G_{peak} = 20.4 + 20 \times \log_{10}(D\,f) + 10 \times \log_{10}(h)$$

where,

D	Antenna diameter [m]
η	Antenna efficiency.

Recommendation ITU-R F.699-4 specifies the reference radiation pattern for radio-relay system antennas operating in the range from about 1 to 40 GHz. For most typical FS antennas, the ratio D/l is less than 100, however, there are some FS stations in use that employ larger antennas (e.g., 1.8 m diameter), which require the tighter sidelobe specification to be used.

The AP29 reference radiation pattern applies to earth stations operating in the fixed satellite service. The equations are identical to those presented in ITU-R F.699-4. For the LEOSAT-1 system, the probability of the minimum operational elevation angle value occurring in the direction of the FS transmitter station is very low. For the purpose of determining the long-term interference value, the minimum LEOSAT-1 terminal receive gain (–3.2 dB) was used in the exclusion zone calculations. The standard LEOSAT-1 user terminal has a receiver noise of –87 dBm (assuming a 500 MHz receiver bandwidth). Assuming a 6% single source interference allowance, the FS transmitter interference should not exceed –99.2 dBm.

Annex 2

ANALYSIS OF THE FEASIBILITY OF FILTERING TO ENABLE OPERATION OF 500 MHZ NGSO FSS DOWNLINKS IN THE PRESENCE OF FS INTERFERENCE IN THE UPPER 40 MHZ

The figure below shows an example of the magnitude response of a typical NGSO user receiver filter (matched filter) in the top 40MHz of the NGSO FSS downlink band. The modulation is 8-PSK with raised cosine spectrum pulse shaping with an excess bandwidth of 25%. Notice that the filter falls off relatively slowly until the very edge of the frequency band. The average attenuation in the band is approximately 5 dB. This does not provide sufficient mitigation to interference that might reside in this spectrum.

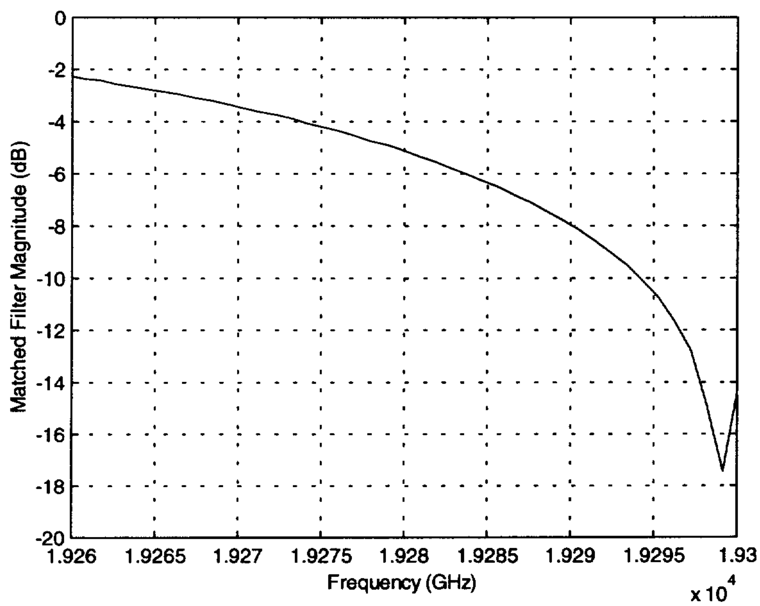


Figure 1. Receiver Filter Magnitude Response at Edge of Band

One proposed mitigation technique is for the user equipment to filter out the top 40MHz in areas where FS interference is present in this band. Figure 2 shows the power spectrum of the data signal, filtered data signal, and the magnitude response of the null filter used to provide 30 dB of attenuation in the bandwidth of interest. However, this filtering degrades the performance of the link in two ways. First, approximately 8% of the signal of interest is removed which results in a reduction of the received signal power. Second, and more critical, the remaining signal power is spread over multiple symbol times causing inter-symbol interference (ISI). This ISI distorts the desired signal such that it can not be properly demodulated.

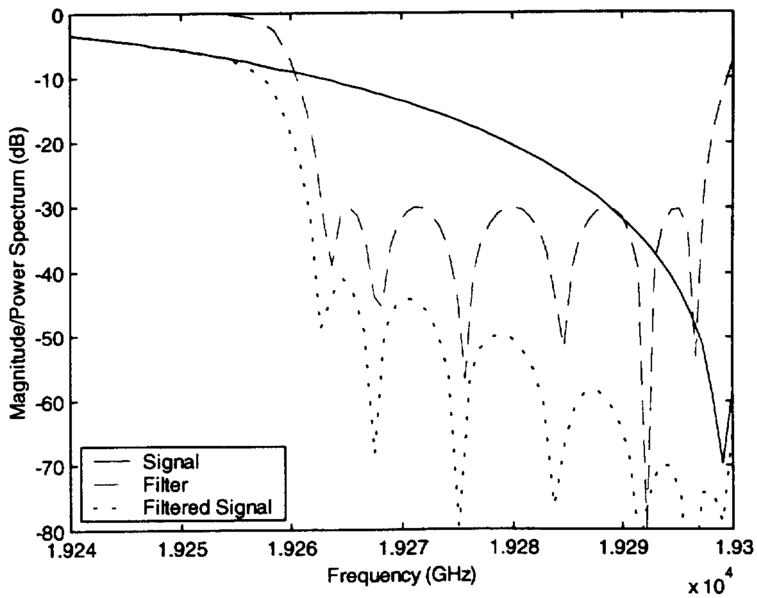


Figure 2. Power Spectrum of Signal and Magnitude Response of 40 MHz Null Filter

For ISI-free demodulation, the post-filtering pulse must have zero crossings at the time stamps corresponding to adjacent symbols. After the filtering suggested in Figure 2 2 this is no longer the case. Non-zero values at these time stamps cause the transmission of one information symbol to interfer with the reception of another information symbol. Figure 3 shows the energy in the inter-symbol interference for neighboring symbol times. The values shown are normalized such that unity corresponds to the energy, E_S, of an undistorted symbol (i.e, without the 40 MHz nulling filter).

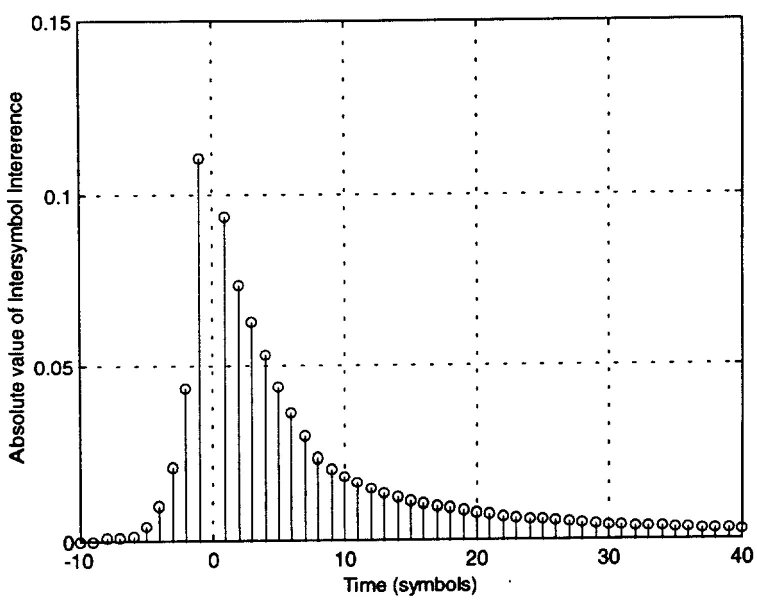


Figure 3. Inter-Symbol Interference

It is possible to estimate the distortion loss by modeling the ISI as additive white Gaussian noise with power density I_O. In this case, $N_{eq} = N_O + I_O$, where N_{eq} is the equivalent noise density and N_O is the standard receiver noise power density. The signal-to-self-interference power ratio E_s/I_O is computed by summing the squared values of the individual ISI samples, Figure 3, and taking the inverse. This is combined with knowledge of the required (threshold) E_s/N_{eq} (10.9 dB in the case of the standard Teledesic downlink), to estimate the degradation. First, consider the following equation used to compute the combined effects of the ISI self-interference density (I_O) and the receiver noise density (N_O):

$$E_S/N_{eq} = E_S/(N_O + I_O) = \frac{1}{1/E_S/N_O + 1/E_S/I_O}$$

Note that this assumes the ideal condition where no external interference is present. We want to determine the new E_s/N_O required such that, when combined with the ISI, we obtain the required (threshold) value. Rearranging terms produces the following equation,

$$E_S/N_O = \frac{1}{1/E_S/N_{eq} - 1/E_S/I_O}.$$

The degradation is computed by subtracting the threshold E_s/N_{eq} from the new required E_s/N_O. When this analysis is performed for the filter shown in Figure 1 that produces the ISI illustrated in Figure 3, the degradation is 3.3dB.

Conclusion:

This analysis has shown that it is not feasible to operate a 500 MHz NGSO FSS downlink when FS interference is present in the upper 40 MHz of the band. A user terminal's matched filter does not provide enough attenuation to filter out FS signals present. Use of additional filtering to attenuate FS interference in the upper 40 MHz of the frequency band is ineffective at solving this problem. In addition to reducing the received signal power, such filtering would introduce inter-symbol interference that significantly degrades the performance of the link. Analysis based on a white noise interference model indicates that this degradation will exceed 3dB.

Annex 3

ANALYSIS OF SOME IMPACTS OF REDUCED BANDWIDTH CARRIERS ON NGSO FSS NETWORK CAPACITY AND STATISTICAL MULTIPLEXING EFFICIENCY

This annex analyzes the effects of reduced bandwidth carriers on the downlink capacity of NGSO FSS systems from a statistical multiplexing point of view and demonstrates that this would result in a downlink capacity loss of potential significance depending on the scenario under consideration.

Broadband NGSO FSS networks will take advantage of the packet-switched environment by allowing a set of channels to be shared -- on a packet-by-packet basis -- among a large set of users, with capacity assigned on demand to meet the users' current needs. This is in contrast with dedicated channel assignment mechanisms typically implemented in circuit-switched systems. This flexibility allows an NGSO FSS network to efficiently handle a wide variety of user needs: from occasional use to full-time use; from low data rates to high data rates; from constant bit rate to highly variable bit rate. Such a mix of broadband traffic will inevitably lead to bursty traffic characteristics.

Reduction in Statistical Multiplexing Efficiency with Reduced Bandwidth Carriers

To effectively demonstrate the channelization effect that results from reduced bandwidth carriers on the downlink performance from a capacity standpoint, we appeal to two important mechanisms: statistical multiplexing and traffic aggregation. The first mechanism, statistical multiplexing, is a technique that allows for efficient resource utilization in packet-switched networks. Suppose a resource is used by a set of bursty sources that have an aggregate peak rate of p packets/second and an average rate of m packets/second. In the worst case, requests from all sources could arrive simultaneously, so a conservative resource allocation scheme is to serve them at a rate of p packets/second. This approach, however, is not efficient since the server operates below full capacity when less than p packets/second are arriving. A more viable approach would be to buffer some of the resource requests, and serve them at a rate C packets/second which is smaller than p, but larger than m. As C gets closer to p, the QoS (average delay or block rate) is reduced, but resources are wasted. On the other hand, a smaller C implies more efficient resource utilization, but results in QoS degradation, seen by the user as either an increase in average delay or an increase in block rate. Accordingly, given the level of QoS requested by the source, the appropriate value of C is computed to satisfy the request. In general, the ratio of the service rate C to the mean rate m required to maintain a specific level of QoS is proportional to the variance of the arriving traffic stream.

More specifically, we consider a self-similar traffic arrival process A_t, which denotes the amount of traffic offered in the time interval of length t:

$$A_t = mt + \sqrt{am}Z_t$$

We call the process fractional Brownian traffic if Z_t is a normalized fractional Brownian motion. The process has three parameters m, a, and H with the following definitions: m is the mean traffic arrival rate, a is a variance coefficient, and $.5 <= H < 1$ is the Hurst parameter of Z_t.

The Hurst parameter partially characterizes the burstiness of a traffic stream. Let X be a covariance stationary stochastic process with a given mean and variance. If X has an autocorrelation function of the form

$$\mathrm{r}(k) \propto k^{-\beta} \text{ as } k \rightarrow \text{infinity}$$

where $0 < \beta < 1$, i.e. a hyperbolically decaying autocorrelation function, then the Hurst parameter, H, which quantifies the long range dependence characterization of the process X, is related to beta through $H = 1 - \beta/2$. Note that H has a lower bound of 0.5 and an upper bound of 1.0. Less bursty traffic streams typically have a Hurst parameter closer to 0.5 and more bursty traffic streams have a Hurst parameter closer to 1.0.

The traffic arrival process arrives into a buffer of size x. Our goal is to determine the service rate C such that the buffer overflow probability does not exceed ε (this constitutes the QoS specification). A lengthy derivation yields

$$C = m + \left[\kappa(H)\sqrt{-2\ln\varepsilon}\right]^{1/H} a^{1/(2H)} x^{-(1-H)/H} m^{1/(2H)}$$

$$\text{where } \kappa(H) = H^H(1-H)^{1-H}$$

The above equation clearly demonstrates the proportionality of the required service rate C to the variance coefficient a for a fixed mean arrival rate m.

Reduction in Traffic Aggregation Efficiency with Channelization

The second mechanism, aggregation, is a simple consequence of the law of large numbers; aggregating more traffic sources results in decreased variability[1] of the aggregated traffic. In the above mathematical framework, as we aggregate more traffic source the variance coefficient a decreases.

The combination of these two mechanisms results in the following principle: If N traffic streams are arriving into a server of capacity C, it is much more efficient to apply this service rate to the aggregate of the traffic streams than to dedicate a portion C/N of the service rate to each of the arriving streams. In other words, more average traffic can be

[1] One measure of variability is the ratio of the variance to the mean.

served at a given QoS with a single large server at service rate C, than with N servers each at service rate C/N.

Effect of Channelization on Downlink Capacity and QoS

For illustrative purposes, a simulation was performed to contrast the average capacity throughput carried by a single downlink beam with 1 x 300 Mbps, 2 x 150 Mbps, 3 x 100 Mbps, and 6 x 50 Mbps channels under the following assumptions:

- Self-similar traffic arrival process with parameter $H = 0.8$
- Buffer size of 200 Mbytes
- Cell Loss Ratio specification of 10^{-7}

The resulting average capacity throughput is summarized in the following table:

Number of Channels per beam	*Single 300 Mbps Channel*	*Two 150 Mbps Channels*	*Three 100 Mbps Channels*	*Six 50 Mbps Channels*
Total Avg Capacity Throughput	162	139	124	100
Delay (ms)	X	1.7X	2.4X	4.1X

The above results indicate that a single 300 Mbps channel downlink beam can sustain a packet-based average traffic load of 162 Mbps, while a downlink beam with six 50 Mbps channels can sustain a mean traffic load of only 100 Mbps with the same QoS; **a capacity loss of 38%.** There is also an additional delay incurred as indicated in the table above since packets remain in queues longer due to the lower service rate.

A Specific Example

Figures 1-3 demonstrate the principle with a specific example. Figure 1 shows an aggregate traffic stream served with a 300 Mbps channel. The QoS is defined in this case by the percentage of time that the traffic requests exceed the channel size. Here the required QoS is defined as a 1% block rate. Note that with packet traffic these "blocks" could be considered delays since the traffic may be buffered and served after the aggregate traffic level has subsided below the maximum channel size.

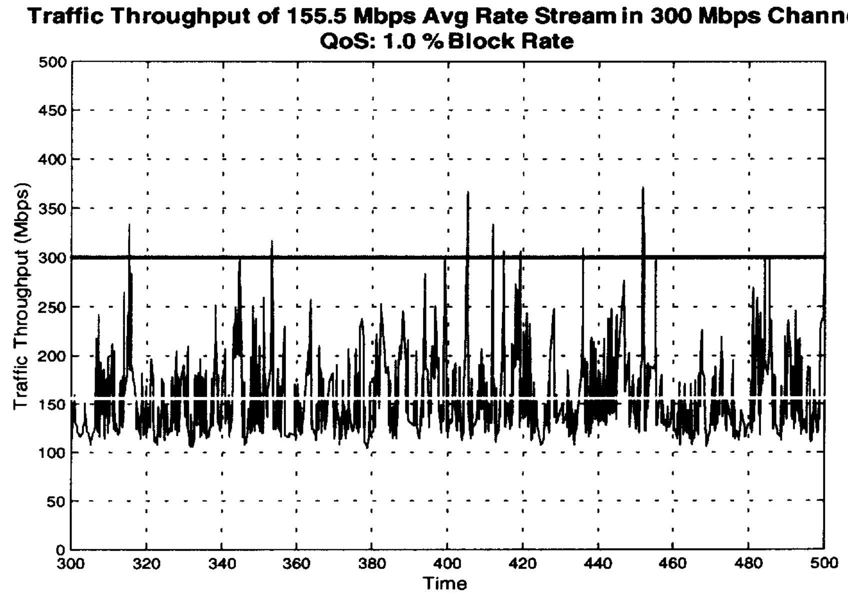


Figure 1 Traffic Throughput of 300 Mbps Channel with 1% Block Rate

Figure 2 shows the resulting QoS when the average traffic stream of 155.5 Mbps from Figure 1 is divided up into six separate traffic streams each with an average equal to 26.1 Mbps, one sixth of the original stream average. Each stream is served with a 50 Mbps channel which is one sixth the original channel size. Note that the QoS of this smaller traffic stream has degraded significantly from an approximate block rate of 1% to a block rate of about 7.4% because of the increased variability of the smaller traffic stream.

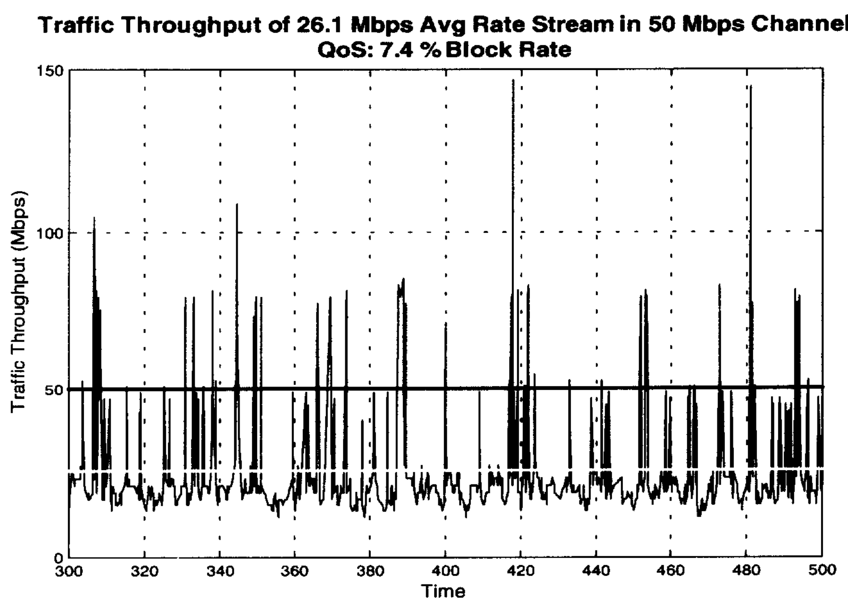


Figure 2 Traffic Throughput of 50 Mbps Channel with 7.4% Block Rate

Figure 3 demonstrates the loss in statistical multiplexing gain when channelizing a 300 Mbps channel into six separate 50 Mbps channels. In order to maintain the QoS level at a 1% block rate, the average traffic stream served by the 50 Mbps channel must be reduced from 26.1 Mbps to 15.5 Mbps. The combination of six such channels could then only sustain an average throughput of 93 Mbps, which is a 40% loss in average capacity throughput for this specific example.

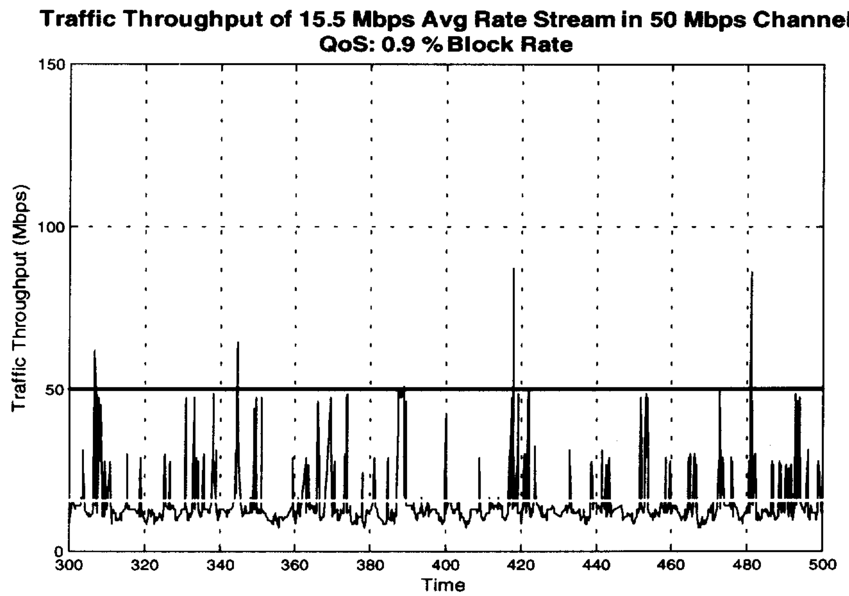


Figure 3 Traffic Throughput of 50 Mbps Channel with 0.9% Block Rate

Annex 4

Technical Explanation of Why the Beams Sharing a Common Aperture must operate Synchronously

In a multiple beam array all the beams share the same aperture. Because they also share the same high power amplifier, each signal affects the others in the form of a random phase shift. When all of the burst transmissions for a single packet per beam, begin and end at the same time, the phase offset is constant throughout the signal in each beam. This random phase offset combines with a random phase shift introduced by the propagation environment to produce a constant phase offset in the received signal at the user equipment. (The propagation environment is sufficiently stable over the short time it takes to burst transmit a single data packet using 500 MHz.) This phase offset is estimated in the process of demodulating the signal in the user equipment.

Problems would occur if different beams were to start bursting asynchronously. Figure 2 illustrates the framing for two beams at different bandwidths. A 460 MHz bandwidth beams would take more time to burst a fixed-length packet than the 500MHz beam. Even if the frames of the two beams start synchronously soon each will be bursting at different start times. This would introduce random phase shifts at one or more points during a packet transmission burst as indicated by the arrows in Figure 2. This would require the demodulator in the user equipment to estimate multiple random phase shifts to enable the demodulation of the burst. This is not feasible in ubiquitous, low cost user equipment.

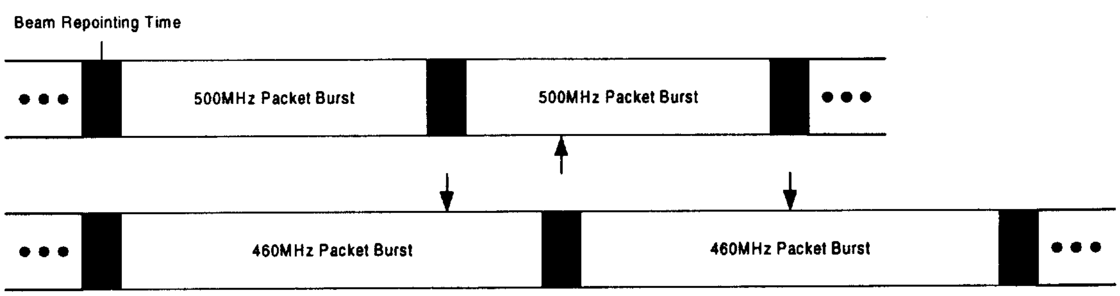


Figure 2. Downlink Burst Framing Example.

Annex 5

Adding the Capability to use 460 MHz Beams to a 500 MHz NGSO Downlink Would Result in a 50% Reduction in Packet Efficiency

To accommodate a 460 MHz bandwidth mode would result in a significant inefficiency because the normal (500 MHz) packets would each have to be sent as two 460 MHz packets. This is because 8% of the bits that could be sent on a 500 MHz beam will still be left at the end of the packet frame on a 460 MHz beam. These remaining bits must then be transmitted during the next packet frame with their own preamble and most of the bit slots unused. This is a huge inefficiency that results in a 50% reduction in the effective capacity of the 460 MHz beams.

For example, say that the payload size in a normal packet is 900 bits and the preamble is 100 bits. Assuming that in one frame period, 1000 bits can be sent using a 500 MHz downlink, then, theoretically 920 bits can be sent using a 460 MHz downlink. Then the first of the two 460 MHz sub-packets would contain 100 preamble bits and 820 payload bits, leaving 80 bits plus another 100-bit preamble to be sent on a second sub-packet. The packet efficiency (ratio of payload bits to total bits) in this case has been reduced from 0.9 or 90% in the 500 MHz case to ((820 + 80)/(1000 + 1000)) = 0.45 or 45% in the 460 MHz case. The part of packet frame 2 labeled "empty" in the figure below illustrates this significant spectral wastage.